Coordinating Aircraft During NASA Airborne Science Field Campaigns

H. Michael Goodman[1], Rich Blakeslee[1], Kathryn Regner[2], Paul Meyer[1], Helen Conover[2], John Hall[2], Matt He[2], Michele Garrett[2], Jared Harper[2] and Tammy Smith[2]

[1] National Aeronautics and Space Administration
[2] University of Alabama in Huntsville

***Abstract* - The NASA Real Time Mission Monitor (RTMM) is a situational awareness decision-support tool that integrates real time aircraft tracks, aircraft waypoints, satellite imagery, radar products, surface observations, model output parameters and airborne remote sensing variables in an easy to use and view web-based application. RTMM optimizes real time decision-making for mission scientists, pilots, mission managers, instrument scientists and program managers through the delivery and display of up-to-date mission information (e.g., the weather, spacecraft, and the location, altitude and heading of the aircraft). The second generation version of RTMM is now fully integrated into a web browser portal and no longer relies on the standalone Google Earth application. The Real Time Mission Monitor is a proven tool having been used in many field experiments from arctic forest fire missions to hurricane eye penetrations as well as tracking the oil slick from British Petroleum (BP) Deepwater Horizon oil well blowout.**

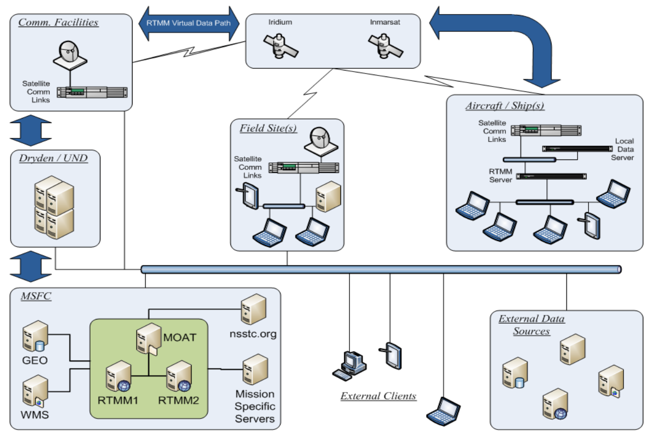

Fig. 1. The RTMM system topology is highly distributed but connected through many network links and communication channels. Large blue arrows show data flow between RTMM servers at NASA Marshall Space Flight Center and the remote observational assets.

I. Introduction

The NASA Real Time Mission Monitor (RTMM) is an interactive visualization application that provides situational awareness and equipment / asset management to enable adaptive and strategic decision-making during airborne field experiments (although it can be easily applied to any activity requiring real time situational awareness). RTMM integrates satellite imagery, radar, surface and airborne instrument data sets, model output parameters, lightning location observations, aircraft navigation data, soundings, and other applicable Earth science data sets. The integration and delivery of this information is made possible through data acquisition systems, network communication links, and network server resources. RTMM uses either the Google Earth web plug-in and/or World Wind application for the user visualization display (Fig. 1).

Through the Earth Science Technology Office (ESTO) Advanced Information System Technology (AIST) funding, we are transforming the first generation RTMM prototype into a powerful science decision-making tool, built upon a service oriented architecture that seamlessly integrates multiple applications for facilitating the monitoring and management of airborne assets in NASA Earth science ground validation and field campaigns. This 2nd generation RTMM operates from a web portal utilizing applications on a common framework for science data visualization and airborne mission management. The improvements brought about by development of this RTMM 2nd generation system provides mission planners and airborne scientists with enhanced decision-making tools and capabilities to more efficiently plan, prepare and execute missions, as well as to playback and review past mission data.

II. Use of RTMM in Airborne Science Field Campaigns

The RTMM was originally developed by NASA Marshall Space Flight Center (http://rtmm.nsstc.nasa.gov) to track and monitor assets during Earth science research airborne field deployments. It grew out of a requirement to chart the position and manage the flights of an Altus uninhabited aerial vehicle but has rapidly expanded to include well over a dozen manned and unmanned aircraft. RTMM has been used in a wide range of airborne science experiments including hurricane flights, arctic tundra fires, soil moisture observations and monitoring and measuring the spread of the oil from the BP Deepwater Horizon oil rig. In August – September 2010, RTMM supported hurricane research flights of the NASA unmanned high-altitude Global Hawk, the NASA DC-8, and NASA WB-57 during the Genesis and Rapid Intensification Processes (GRIP) tropical cyclone field experiment. Deploying aircraft and experiment teams from

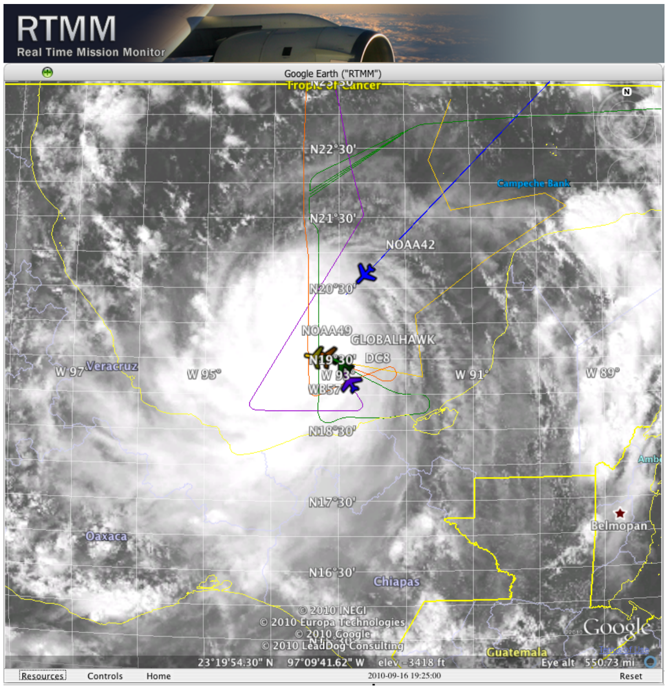

Fig. 2. RTMM captures the well-coordinated flights of a combined five NASA, NOAA and Air Force aircraft over Hurricane Karl on 16 September 2010.

both coasts proved to be an exceptional and challenging test of the system. During the six week GRIP campaign, the RTMM tracked and displayed current weather conditions for multiple aircraft (three NASA, three NOAA, one NCAR, and several Air Force Reserve), including the NASA unmanned Global Hawk at NASA Dryden Flight Research Facility, CA the NASA WB-57 at NASA Johnson Space Center, TX and the DC-8 at Fort Lauderdale, FL (see Fig. 2).

Ancillary applications, such as the integrated multiple window display of model and forecast parameter fields, interactive XChat text exchange capability and the Waypoint Planning Tool proved to be invaluable to science situational awareness and further contributed to mission success. In addition, feedback from users in the field was beneficial for driving new requirements and charting the course for future development. Close pre-mission coordination with the Global Hawk flight team led to using the RTMM in their operations center, which resulted in RTMM being poised to capture the maiden voyage of NASA's new asset flying over the eye of Hurricane Earl.

RTMM was used again in February 2011 for the Global Hawk flights into the northern Pacific and Arctic Oceans during WISPAR – Winter Storms and Pacific Atmospheric Rivers. WISPAR pioneered the first usage of dropsondes from the Global Hawk and RTMM was used both to plan the dropsonde launch locations and monitor their release. In the last five years RTMM has been used in over a dozen different experiments and in each case the functionality of RTMM has grown to match the needs of the science user community. Most recently, in May-June 2011, RTMM was used during the MidLatitude Continental Convective Clouds Experiment (MC3E) [1] with the NASA ER-2, flying out of Offutt Air Force Base, Nebraska and the University of North Dakota Citation and University of Tennessee Space Institute Piper Navajo both based in Ponca City, Oklahoma.

III. Description of RTMM

Tracking these planes is relatively easy; RTMM ingests the real time navigation data as it is transmitted from the aircraft to a central data server at NASA Dryden Flight Research Center or downloads the airplane locations using the FlightAware commercial service. What RTMM uniquely provides to the scientist is the ability to integrate many other ancillary data sets and do it seamlessly with multiple independent user window configurations. For example, we routinely ingest real time NOAA Geostationary Operational Environmental Satellite (GOES) visible, infrared and water vapor images and optionally animate the last few hours of data. The GOES data are useful for experiments over the United States, but for the GRIP experiment RTMM also ingested the Meteosat Second Generation (MSG), which is the European geostationary satellite for views of nascent tropical disturbances emerging off of North Africa. Similarly, for experiments over the Pacific or Asia, we would ingest, display and animate the Japanese Geostationary Meteorological Satellite (GMS) imagery.

Displaying the aircraft track over animated real time satellite images is useful but RTMM also provides the flexibility to add combinations of National Weather Service Next Generation Radar (NEXRAD) reflectivity images, research radar reflectivities (e.g., NASA S-Band polarimetric Doppler radar, X-band and C-band radars), multiple lightning strike surface networks (e.g., Vaisala, National Lightning Detection Network, WeatherBug Total Lightning Network and regional Lightning Mapping Arrays), real time satellite positions, satellite predictions, hurricane tracks, aircraft altitude and pitch and roll, radiosonde and dropsonde observations, aircraft nadir camera pictures, other experiment specific data sets (e.g., buoy reports) and even weather forecast products using standard services such as Open Geospatial Consortium (OGC) Sensor Observation Service (SOS) and Keyhole Markup Language (KML). [2] Standards-based interfaces to this large variety of products makes RTMM the most powerful situational awareness tool for NASA airborne science research experiments. RTMM has rapidly become indispensable for many airborne scientists particularly those that must respond to demanding and dynamic weather events.

A key component in many field campaigns is coordinating the aircraft with satellite overpasses, other airplanes and the constantly evolving, dynamic weather conditions. Given the variables involved, developing a good flight plan that meets the objectives of the field experiment can be a challenging and time consuming task. Planning a research aircraft mission within the context of meeting the science objectives is a complex task because it is much more than flying from point A to point B. Flight plans typically consist of flying a series of transects or involve dynamic path changes when "chasing" a hurricane or forest fire. These aircraft flight plans are typically designed by the mission scientists then verified and implemented by the navigator or pilot. Flight planning can be an arduous task requiring frequent sanity checks by the flight crew. This requires real time situational awareness of the weather conditions that affect the aircraft.

A companion application to RTMM, the Waypoint Planning Tool (WPT) is an interactive Java program that enables aircraft mission scientists to easily develop flight plans (also known as waypoints) with point-and-click mouse capabilities on a digital map draped with real time satellite imagery or weather model forecasts. The Waypoint Planning Tool has further advanced to include satellite orbit predictions and seamlessly interfaces with the Real Time Mission Monitor. Individual flight legs are automatically calculated for altitude, latitude, longitude, leg distance, cumulative distance, leg time, cumulative time, etc. It further incorporates numerous pre-defined flight patterns including figure 4, butterfly, lawnmower and spirals, which are all user-configurable for leg length and direction. The resultant flight plan is provided to the navigator / pilot for review. It is also posted to RTMM and inserted into the menu for all interested scientists to view and track actual flight progress compared to the planned flight track.

An additional strength of RTMM is its availability and ease of use. RTMM is accessed via the Internet and as such users are not confined to using it at just the mission operations center. NASA Program Managers routinely use RTMM to follow the flights from NASA Headquarters. The Global Hawk pilots stationed at the Global Hawk Operations Center in NASA Dryden used RTMM to separately monitor the weather while flying the Global Hawk uninhabited aerial vehicle from their pilot station. Scientists aboard the DC-8 use RTMM to not only track the flight of the DC-8 but to also monitor and coordinate with other research aircraft in the vicinity and to ensure proper flight line placement during polar-orbiting satellite overpasses and dropsonde waypoint locations. An example of its versatility and capability to remotely monitor the real time progress of research flights is the use by a professor and Ph.D.-candidate graduate student to teach tropical meteorology classes using RTMM as a real time classroom visualization tool.

IV. Advances and New Developments

The Real Time Mission Monitor was first developed for use with the standalone Google Earth application. Although successful in this initial implementation, there were several restrictions and impediments that limited its usage. First, downloading, launching and running the standalone Google Earth could be a barrier especially for novice users. Second, to view multiple visualization windows users had to run multiple Google Earth sessions, and third, integrating third party programs was difficult at best.

Through ESTO AIST funding, our goal is to redesign, implement, and operate the RTMM from a web portal utilizing applications on a common framework for science data visualization and airborne mission management. The improvements brought about by RTMM 2nd generation system development provide mission planners and airborne scientists with enhanced decision-making tools and capabilities to more efficiently plan, prepare and execute missions, as well as to playback (animate) and review past mission data.

Using the Google Earth Plug-in application programming interface (API) we transitioned RTMM into a technologically advanced, web-based tool with an attractive, intuitive and highly functional user interface. Using the API means that the end users can run the RTMM application in a web browser, rather than having to install the Google Earth standalone application on their computer. The 2nd generation tool is designed to read and store user configuration information either locally using "cookie" technology or externally to a relational database, using standard services.

One of the significant user interface changes is the development of a "layout manager." The layout manager lets the user pick from many different pre-defined window configurations. The user's computer screen can be subdivided into multiple windows of varying rectangular shapes and sizes. A user can choose a single window or more typically a two, three or four panel display. Within each window, the user may choose to run one of many different RTMM application tools (see Fig. 3.). Typically, a scientist will overlay the aircraft track on a geostationary weather satellite image (e.g., visible or infrared) in one window, while monitoring the aircraft altitude, pitch and roll in another window, viewing a dropsonde skew-T chart or other onboard aircraft real time data stream in a third window and conducting a message chat conversation in a fourth window. The aforementioned examples are just one of many configurations that can be set up.

In addition to using the Google Earth API, the RTMM team is exploring the use of the NASA World Wind KML viewer for use with bandwidth limited Internet connections such as aboard an aircraft or at a remote field site with limited communications. This World Wind web plug-in does not "phone home" at the frequency required by Google Earth.

Extensibility is also provided in the 2nd generation tool that allows end users to provide links to their own content so long

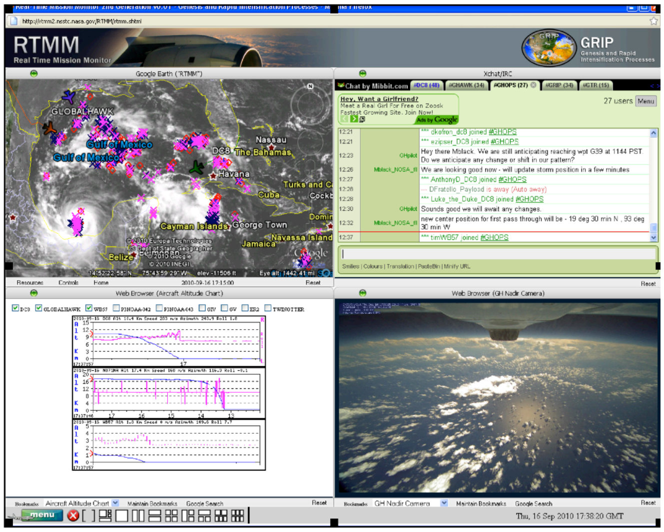

Fig. 3. Four-panel RTMM screen depicting (upper left): 3 aircraft with lightning strikes in magenta; (upper right): XChat discussion of Global Hawk waypoint timing; (lower left): aircraft altitude charts; (lower right): nadir camera view from the belly of the Global Hawk.

as it is provided in a KML-compliant format. Examples include weather model data, National Weather Service watches and warnings, and ship locations. This capability allows the user to store these links in their web browser cookies so that they may be recalled in future RTMM sessions.

RTMM excels at providing visual information in the form of dynamic aircraft tracking and satellite image animations, and real time airborne instrument displays. However, dynamic “on-the-fly” aircraft coordination of research aircraft requires near real time communications. Voice teleconferencing has been tried, but with many scientists scattered in different locations voice telecons are actually ineffective. Background noise, scientists accidentally talking over each other or interrupting conversations are the usual problems. Bandwidth is another issue, especially while on a plane with narrow bandwidth and limited opportunities to communicate to the ground. The most effective means for multiple people to communicate in these situations is through a text-based messaging system. The integration of a text messaging or a chat system to facilitate remote conversations and discussions has proven to be successful.

It was previously mentioned that it does not matter where the users are located. Since RTMM relies on the Internet, its web-based users may be scattered across the country or even overseas. Mission scientists are located at the mission operations center; instrument scientists may be aboard the aircraft, while other team members may be located back at their home institutions. A messaging system (i.e., Internet Relay Chat system - IRC) enables remote users to engage in running text conversations to exchange information, ideas, and real time mission planning and management. RTMM utilizes the shareware XChat system. XChat permits users to join multiple IRC channels (chat rooms) at the same time, talk publicly or privately in one-on-one conversations. Typically, RTMM administrators set up default chat rooms during an individual airborne science experiment. One chat room is assigned for each aircraft, another for science discussion, and another for technical communication issues. Chat users are free to hop from chat room to chat room joining in on conversations of interest. Coordination of the aircraft to achieve the science goals is realized through the combined RTMM visual data windows and the text based XChat window.

Another goal is to allow the Mission Scientist from an upcoming experiment to directly configure RTMM assets specifically for the experiment. The RTMM development team has been working toward a web-based mission designer tool that will allow a Mission Scientist to configure and save the core services needed for an upcoming campaign. This tool is intimately tied to the RTMM relational database catalog using an XML-based service oriented architecture. For an upcoming mission the scientist defines the spatial extent of the campaign, dates of the campaign and identifies the aircraft, satellite, and ground-based resources they wish to use during the experiment. They may also identify links to non-core RTMM resources such as model data specific to that campaign, or ground-truth sensors that may be placed in its own category. This mission configuration may then be saved to the relational database system for later automated recall by the other experiment users.

Key to the success of the RTMM 2nd generation system is the services interface (see Fig. 4). This interface provides the common access between the relational database and the core RTMM tools such as the mission designer, the visualizations, resource tracker, Waypoint Planning Tool and external databases.

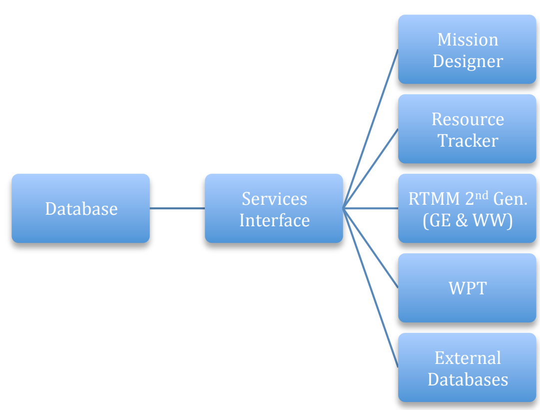

Fig. 4. RTMM Services Oriented Architecture

V. Conclusion

We have described the basic functionality and features of the Real Time Mission Monitor. This software application has become a staple of many NASA airborne science missions. The ability to “see” the plane’s location, view real time data streams and simultaneously communicate with remotely located science team members is the key to what makes the RTMM system a powerful tool for conducting airborne science.

As RTMM gained acceptance in the Earth science community, it became apparent that in order to sustain growth, we had to move towards autonomous mission support. i.e., to provide remote support to the airborne experiment without a “person in the field”. Early campaigns that RTMM supported always required that the RTMM team deploy a person to the mission operations center to ensure smooth operations of the RTMM functions. This was done during the NASA African Monsoon Multidisciplinary Analyses [3] experiment in Cape Verde, the dual Arctic Research of the Composition of the Troposphere from Aircraft and Satellites [4] campaigns in Fairbanks, AK and Cold Lake, Alberta, and GRIP in Ft. Lauderdale, FL. A significant accomplishment towards reaching autonomous mission support was achieved as proof of concept, during the Light Precipitation Validation Experiment in Finland in late 2010. It was further refined in 2011 with the Winter Storms and Pacific Atmospheric Rivers (WISPAR) at NASA Dryden, the Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) [5] at NASA Johnson Space Center and during the MC3E flights when no RTMM personnel were sent into the field.

RTMM remote support was made possible due to technology improvements resulting from ESTO AIST funding. The AIST funding has provided the means for the RTMM development team to infuse new technologies into the RTMM system. These technologies include a service-oriented architecture, a layout manager, a mission configuration or design tool, the Waypoint Planning Tool, and extensibility features.

VI. References

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